

SOFT GLUON RESUMMATION FOR SHAPE VARIABLE DISTRIBUTIONS IN DIS

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We discuss the procedure to resum large logarithms to all orders in the differential distributions for DIS event shape variables $\frac{\tau}{\sigma} \frac{d\sigma}{d\tau}$. We describe results for two variants of the thrust variable, both defined wrt the boson axis in Breit frame but with differing normalisations.

1 Introduction

Event shape variables in e^+e^- reactions have long been the subject of much attention from theorists and experimentalists proving popular tools for the extraction of α_s as well as for the study of non-perturbative (power) corrections. In the last few years such attention has also been focussed on similar variables in DIS with experimental studies being carried out by both the H1¹ and Zeus collaborations.² In this regard one area of investigation involves the study of differential distributions in shape variables τ which have the perturbative expansion

$$\frac{1}{\sigma} \frac{d\sigma}{d\tau} = A_1(\tau, x)\alpha_s + A_2(\tau, x)\alpha_s^2 + \dots \quad (1)$$

While, in the above equation, the coefficient A_1 is obtainable through an analytical calculation, A_2 can be provided by NLO Monte Carlo programs DISENT³ and DISASTER++.⁴ The variable x is the standard Bjorken variable. At present, experimental studies are confined to comparing the above truncated expansion to data.¹ The findings are that while such a comparison is viable for larger values of τ it gets progressively meaningless as we go to the small τ region. The perturbative results appear to diverge at small τ instead of turning over as indicated by the data.

This problem is familiar from e^+e^- distributions. Essentially the perturbative coefficients above have a leading behaviour (in the small τ region)

$$A_n(\tau, x) \sim \frac{1}{\tau} \ln^{2n-1} \left(\frac{1}{\tau} \right) + \dots \quad (2)$$

At small τ the smallness of α_s is more than compensated by the large $\ln(1/\tau)$ terms which accounts for the divergent behaviour of fixed order results in that

regime. In what follows we shall also refer to the integrated *shape cross section*

$$R(\tau) = \int_0^\tau \frac{1}{\sigma} \frac{d\sigma}{d\tau'} d\tau'$$

for which for every power of α_s there are up to two powers of $\ln(1/\tau)$ (henceforth denoted by L). The differential distribution can be obtained from R by straightforward differentiation.

The leading $(\alpha_s L^2)^n$ behaviour in the perturbative prediction for R is transparently associated with n soft gluon emission and the absence of complete Bloch-Nordsieck cancellations. Such terms are free from any x dependence since soft gluon emission does not change significantly the momentum fraction of the incoming projectile. However there are other sources of large logarithms apart from purely soft emission. These include running coupling effects and hard collinear emissions. It turns out that hard collinear emissions on the incoming leg in DIS are responsible for terms starting at $(\alpha_s L)^n$ (single logarithmic level) with coefficients which are x dependent.

Clearly in order to obtain meaningful perturbative results, one is required to try and resum these large logarithms to all orders in perturbation theory. In this regard the only new feature of the DIS resummation in comparison to e^+e^- shape variable resummation is the above mentioned x dependent single logs. Their resummation is possible since they are of leading log DGLAP type and lead to a change of scale in the parton distribution, or the emergence of the factor $\frac{q(x, \tau Q^2)}{q(x, Q^2)}$ in the final result.⁵ The other aspects of the resummation are mainly familiar from experience with e^+e^- variables, though the details differ from variable to variable. Note that in writing the factor $q(x, \tau Q^2)$ we have also implicitly included the contribution from incoming gluons.

2 Definitions

We consider below the following two definitions of the thrust variable in the Breit current hemisphere:

$$\tau_Q = 1 - T_Q = 1 - \frac{2}{Q} \sum_{i \in H_c} |\vec{P}_i \cdot \hat{n}| \quad (3)$$

$$\tau_E = 1 - T_E = 1 - \frac{\sum_{i \in H_c} |\vec{P}_i \cdot \hat{n}|}{\sum_{i \in H_c} |\vec{P}_i|} \quad (4)$$

where the unit vector \hat{n} denotes the photon direction in the Breit frame and the sum is over all particles in the current hemisphere H_c . The definitions differ

only in normalisation but we find that this significantly affects the resummation both in procedure and results.⁵ The latter definition, involving normalisation to the current hemisphere energy, is only infrared safe provided one imposes a minimum energy cut-off in H_c .

3 Results and Conclusions

The resummed result for the contribution to F_2 from events with $1-T < \tau \ll 1$ (where τ is now used to denote τ_Q or τ_E) is given by

$$R(x, Q^2, \tau) = x \left[\sum_{q, \bar{q}} e_q^2 q(x, \tau Q^2) + C_q(x) + C_g(x) \right] \Sigma(\alpha_s, L) \quad (5)$$

Here C_q and C_g are $\mathcal{O}(\alpha_s)$ constant pieces from incoming quark and gluon sectors respectively and they are different for τ_Q and τ_E . Additionally one has the form factor

$$\Sigma(\alpha_s, L) = \exp[Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \dots] \quad (6)$$

in which we control all terms of the type $\alpha_s^n L^{n+1}$ and $\alpha_s^n L^n$. In other words the functions g_1 and g_2 are explicitly computed⁵ while g_3 is unknown. All these functions also depend on the variable under consideration and hence are different for the different thrust definitions presented.⁵ As discussed previously, all x dependent logarithms have been resummed in the parton density function $q(x, \tau Q^2)$ and the resulting form factor is now x independent.

One can expand this formula to $\mathcal{O}(\alpha_s^2)$ and compare the results at small τ to those from fixed order Monte Carlo programs. On doing so we find reasonable agreement with DISASTER++ but disagreement with DISENT. The exact nature of this disagreement is detailed in our paper.⁵

Our result valid for small τ can then be matched to NLO estimates from the Monte Carlo programs. The matching procedure extends the range of applicability of the resummed calculation to larger τ values where non logarithmic pieces in the fixed order result are significant. The essential idea of matching is simple: one simply adds the resummed and NLO calculations and then subtracts the pieces corresponding to double counting. Schematically we can write

$$R_{\text{mat}} = R_{\text{res}} + (R^{\text{NLO}} - R_{\text{res}}^{\text{NLO}}) \quad (7)$$

In the above R_{mat} denotes the matched shape cross section and R_{res} the resummed calculation, while the piece $(R^{\text{NLO}} - R_{\text{res}}^{\text{NLO}})$ takes care of adding terms in the NLO result for R that are absent in the resummed result expanded to

the same order. In practice matching is a technically involved procedure and different matching schemes can be used which differ on how to treat subleading logarithmic terms. Our preferred matching prescription is presented in the full paper.⁵

Once the resummation is carried out and matched to fixed order, we have the best available perturbative prediction at hand. This prediction is at least as good as the NLO Monte Carlo estimate over the entire range of shape variable values and is far superior at small τ . However we have not addressed another potential source of uncertainty, namely power behaved corrections.

The main effect of power corrections will be to simply shift the perturbative distributions by an amount proportional to $1/Q$ towards larger τ values. An exception to this rule is the current jet broadening variable where the perturbative prediction is squeezed and shifted due to non-perturbative effects. The amount of the shift for the thrust variables is identical to the power correction to the corresponding mean values which have been computed.⁶

Other variables that are being studied at the moment include the thrust defined wrt the actual thrust axis (normalised to E), the current jet-mass and the C parameter.⁷ When resummed results for these distributions become available they should also be matched to NLO and adjusted for power corrections after which detailed phenomenological analysis and comparisons with data should become possible.

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